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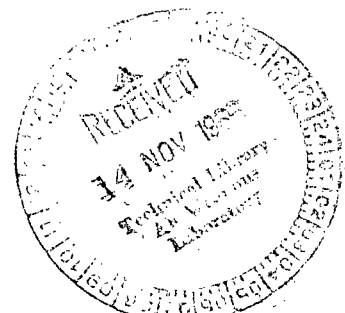
NASA TN D-3704

A GENERALIZED SATELLITE TELEMETRY DATA SIMULATION PROGRAM

by Bernard G. Narrow and Richard C. Lee

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Greenbelt, Md.



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ERRATUM

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**by Bernard G. Narrow
and Richard C. Lee**

Enclosed herewith is a corrected copy of page 11 containing Figure 5, which had been omitted.



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

This document describes a Data Simulation Computer Program which generates test tapes to be used for debugging or testing satellite telemetry computer programs. Test tapes may be generated for all presently defined satellite projects. Besides being used directly by programmers, analysts, and experimenters, the test tapes can be a valuable aid to NASA personnel responsible for attesting to the adequacy of computer programs developed under contract. Over-all benefits offered by the Data Simulation Computer Program are a substantial increase in the degree of assurance that a given computer program is adequately debugged prior to actual use, a reduction in the effort required by the programmer in generating test data, the elimination of erroneous test data due to clerical errors, and a reduction in the time required for debugging programs.

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INTRODUCTION

Computer processing of satellite telemetry data plays a vital role by assisting the experimenter in deducing the maximum amount of information from a given experiment. Typically, computer processing is employed in the following stages:

First Stage - After the analog data recorded at the world-wide network of data acquisition stations is converted to a digital tape suitable for computer processing, the data are edited, partially verified, and reformatted by the computer.

Second Stage - The edited data, consisting of a mixture of multiple experiments in the satellite, is decommutated; i.e., segregated in the computer by related experiments for recording on separate magnetic tapes.

Third and Subsequent Stages - The separate experiment data tapes are subjected to a number of computer programs peculiar to the given experiment data. Normally the functions performed are data validation, calibration, smoothing, curve fitting, interpolating, time and spatial correlation, and data display.

Each of the stages described uses one or more computer programs, differing from one satellite to another and from one experiment to another. For the Orbiting Geophysical Observatory (OGO) series satellites which have 20 experiments each, it is conservatively estimated that at least 70 computer programs were prepared for each of the satellites.

Many different groups are involved in the preparation of computer programs. The Information Processing Division at the Goddard Space Flight Center is responsible for the programs associated with the first two stages and partially with the third and subsequent stages described above. Experimenters, both those within GSFC and those affiliated with other government agencies and universities, are responsible for the bulk of the programs pertaining to the third and subsequent stages. In a large percentage of cases, the actual programming is done under contract.

PROGRAM TESTING

Computer programs vary considerably both in size and complexity. Common to all programs, however, is the task of debugging or testing each program to determine that the program structure is logically correct and that all instructions are correct and properly interrelated. Program testing is not only one of the more important factors in developing operational computer programs, but also is perhaps the most prone to underestimation of difficulty and time necessary for completion. Because of the many combinations and permutations of conditions inherent in a given program, it is practically impossible to test all possible conditions which may arise in actual practice. As a result, it is not uncommon that a program which has been operating successfully for many months is one day found to be inoperative because of a rare set of conditions which was not properly covered in the computer program.

To debug programs that are to process satellite telemetry data, one or more of the following sources of data have been used:

- Data generated manually by the programmer,

- Data acquired from the satellite during ground testing, and

- Actual data tapes acquired from previous satellites which have the same basic telemetry format.

The first two sources have a major limitation in that the data obtained therefrom do not adequately reflect the perturbations present in actual telemetry data. Such perturbations, or noise, can be directly introduced in any of the following links between the sensing of the data in the satellite and the subsequent input of the data to the computer:

- Experiment noise,

- The satellite telemetry system,

- The satellite tape recording system,

- The free space channel between the satellite and the ground acquisition station,

- The receiving and ground recording systems at the ground acquisition station, and

- The signal conditioning and conversion systems at GSFC.

The use of the actual data from previous satellites to debug programs for future satellites partially overcomes the above limitation, but it too is of limited utility. In many cases, none of the data available from previous satellites have a suitable format or have been obtained via the same set of data links as the given satellite. Another limitation is that information concerning the specific type and location of the noise perturbations within a given data tape is not available to the programmer. Hence, it is possible that the program will not correctly detect a particular perturbation present in the data and that the programmer will not be aware of this deficiency.

Since the previously described sources do not permit computer programs to be debugged with a high degree of confidence, another source has been developed, namely, a Data Simulation Computer Program. Through this program, data can be made available to the programmer which will realistically take into account the various specified noise conditions. Although this will not provide complete assurance that programs are fully debugged prior to satellite launch, it should permit a substantial increase in the degree of assurance over that which may be achieved from other sources. Other benefits are a reduction in effort required by the programmer in generating test data, a reduction of errors in the test data due to clerical or keypunch errors, and a speed-up in the debugging cycle by circumventing the large degree of dependency on data acquired during ground testing of the satellite.

Besides being used by the programmer and analyst for testing programs prepared by NASA personnel, the Data Simulation Program can be a valuable aid to persons responsible for accepting programs developed by contractor personnel. At present almost complete reliance is placed on the contractor for attesting to the operational readiness of these programs. With the existence of the Data Simulation Program, this need no longer be the case. NASA personnel can specify a comprehensive set of test data to be turned over to the contractor for checking out the programs involved. This could serve as effective criteria for attesting to program readiness prior to acceptance of the program.

DESIGN OF DATA SIMULATION PROGRAM

The objective in the design of the Data Simulation Program was to create a single program which could be used for most future satellites. This called for a very high degree of flexibility in order to account for differences in telemetry systems and formats, varying degrees and types of noise conditions, differences in experiment data characteristics, differences in tape formats used by the different experimenters, etc. Taking all of these factors into account fortunately did not turn out to be a horrendous programming task, and therefore it was feasible to proceed and implement the generalized telemetry data simulation system.

Factors which make it feasible to specify a general set of rules under which different satellite data can be adequately defined by the user are:

- a. Commonality of basic elements; all time-multiplexed satellite telemetry formats can be specified in terms of channels, frames, subcommutation and supercommutation, and related ground time.
- b. A large percentage of experiment data characteristics can be suitably portrayed by a relatively small number of data generation routines, e.g., sine waves, values with known additive noise probability distributions, consecutively increasing or decreasing values, staircase increasing or decreasing value, etc.
- c. Common impact due to perturbations; all satellite data are vulnerable to sensor noise, transmission noise, spacecraft and ground equipment malfunction, and equipment operator errors.

Through the combination of design elements incorporated into the program (e.g., general purpose routines; input parameters to define the telemetry format, data characteristics and noise conditions; and options for users to insert their own coding in the program), all the data needed to comprehensively test the multitude of programs prepared for a given satellite can be provided by the Data Simulation Program, which is described next.

DATA SIMULATION PROGRAM

Presented here is a general system description which highlights the major characteristics of the product. A user's manual is available to provide a full description of the capabilities of the program. The manual contains detailed instructions for preparing input specifications, and illustrates how particular formats and conditions may be defined.

Process Flow

The Data Simulation Program is written for the UNIVAC 1107 computer. As shown in Figure 1, the user provides a deck of punched cards containing all definitions and parameters for the simulation, as well as user subroutines for special computations. The primary output is a digital tape containing the simulated data. A secondary output is a listing containing input parameters, selected data channel and record printouts, errors inserted during simulation, and summary statistics for each simulated file.

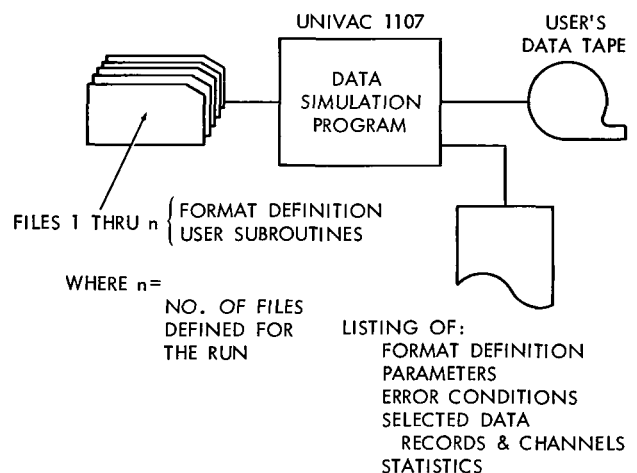


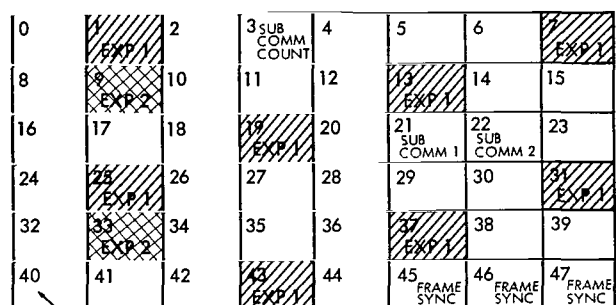
Figure 1—Data simulation flow diagram.

Format Definition

A simulated tape may have up to nine data files, and may be recorded with odd or even parity and with high or low density. The hierarchy of the file organization is file, record, frame, and channel. The length of a given file is governed by the start and stop times, which are input parameters. Record lengths may vary up to 360,000 bits and are determined by the number of frames per record and the number of bits per frame, which are also input parameters.

A frame consists of a number of fixed word length channels which can vary in length from 6 bits up to 36 bits for different files. A channel may contain either experiment data, a frame synchronization pattern, a subcommutator identifier pattern or counter, spacecraft clock readings, ground time, or data quality flags. Any ordering of channels within a frame is permissible, thereby providing full flexibility in data formatting. Two examples out of the many possible formats that can be obtained from the AE-B satellite telemetry format (Figure 2) are illustrated in Table 1.

A comprehensive set of options concerning noise perturbations is also available to the user. Such things as transmission noise, signal blanking, bit slippage, sensor noise, satellite clock and ground time discontinuities, loss of synchronization during analog-to-digital conversion, and equipment operator errors may be selected in any combination, and the composite impact is reflected in the simulated output data. Brief descriptions of the options concerning the experiment data, spacecraft clock and ground time, and the various perturbations are given next.



TELEMETRY CHANNEL NUMBERS

FORMAT CHARACTERISTICS:

- CHANNELS PER FRAME=48
- NUMBER OF SUBCOMMUTATORS=2
- CHANNELS FOR FRAME SYNCHRONIZATION=3

EXP 1 (diagonal hatching)
EXP 2 (cross-hatching)

Figure 2—Atmosphere Explorer-B telemetry format.

Table 1
Two Examples of Format Definitions for Output Tape from Data Simulation Program.

User A, Frame Definition			
Output Tape from Data Simulation Program	Related Channel No. In Satellite Telemetry System (See Figure 2)	Channel Description	Comments
Channel 1	None	Flags Pertaining to Data and Ground Time	These flags simulate those that are produced by the STARS lines.
2, 3, 4	None	Ground Time	Assumes three channels are needed to specify the ground time
5	1	Experiment 1	1st sample from frame i
6	7	Experiment 1	2nd sample from frame i
7	13	Experiment 1	3rd sample from frame i
8	19	Experiment 1	4th sample from frame i
9	25	Experiment 1	5th sample from frame i
10	31	Experiment 1	6th sample from frame i
11	37	Experiment 1	7th sample from frame i
12	43	Experiment 1	8th sample from frame i
13	3	Subcommutator Channel ID	Counts from 0 to 31
14	21 (Subcom 17)	Experiment 3	1st sample from subcom cycle i
15	21 (Subcom 25)	Experiment 3	2nd sample from subcom cycle i
User B, Frame Definition			
1	None	Flags	Same as described above
2, 3, 4	None	Ground Time	Same as described above
5	9	Experiment 2	1st sample from frame i
6	33	Experiment 2	2nd sample from frame i
7, 8, 9	45, 46, 47	Frame sync ID	

Experiment Data Characteristics

Four periodic functions are automatically available to the user. These are sine wave, stair-step, ramp, and constant. Figure 3 illustrates these four functions. Any combination of channels

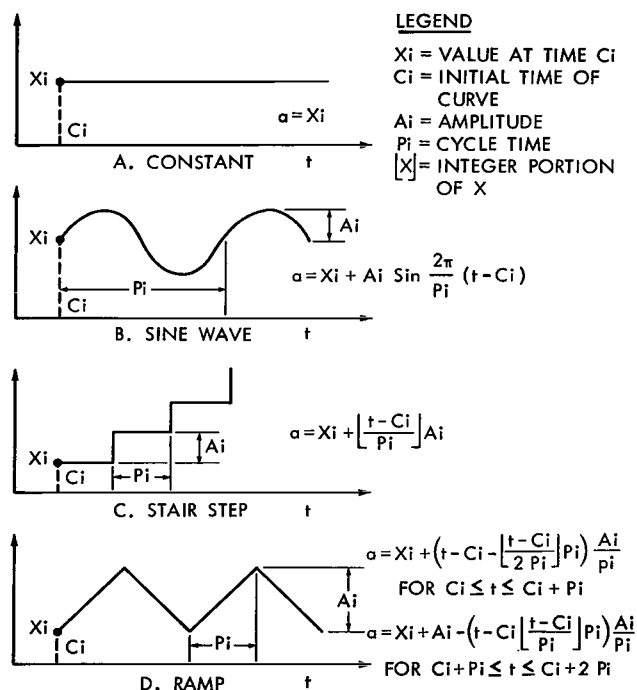


Figure 3—Experiment data curve options.

within a frame may be assigned to a particular curve. The assignment of multiple channels to a given curve is equivalent to supercommutation. In addition, more than one curve can be assigned to a given channel. Hence, if an experiment is to be active for only the last two-thirds of the file, one curve with a constant value of 0 would be specified for the start of the file, and the desired data curve would be specified to begin at approximately the point where one-third of the file has been generated.

Experiment data curves can be defined for subcommutator channels as well as for main frame channels. Here again, full flexibility is provided to the user in selecting combinations of subcommutator channels for different data curves.

In case the four functions incorporated in the program are not suitable, the user may supply a subroutine for generating special functions, or a table-lookup technique may be used. More information on this option is provided in the next section.

Once the value of the curve is computed, sensor noise may be added. The additive noise is assumed to have a normal distribution with zero mean and a standard deviation specified by the user. For example, if a sine wave is chosen, the actual values would be distributed as shown in Figure 4.

Two options are available for generating the data curves. One is the case in which the channel positions in the format defined for the output tape are directly related to the time at which the curve is sampled. The other case is the one in which the time at which the curve is sampled is independent of the channel position defined for the output tape. The former case would likely be selected for simulating a tape which has all of the channels per frame as the actual telemetry system, whereas the latter option is likely to be chosen if the simulated tape is not defined as having the same number or arrangement of channels per frame as the actual telemetry system. In the latter case, a constant time increment, input by the user, is used as the sampling interval for each channel assigned to a given curve. Through the foregoing options and the flexibility permitted in defining the data for a given channel, virtually any format designated by the user, including intermixed

formats as used on the OGO satellites, may be defined in such a manner as to provide realistic data values for the various curves involved.

User Coding

Options exist to permit user coding to generate experiment data curves and data flags. For generating experiment data, the user provides a subroutine called USRSUB. Once each frame, the main program calls the subroutine and provides the current ground time, record number, and frame number. The user subroutine then computes the value of the curve for insertion in the output tape record and then returns control to the main program.

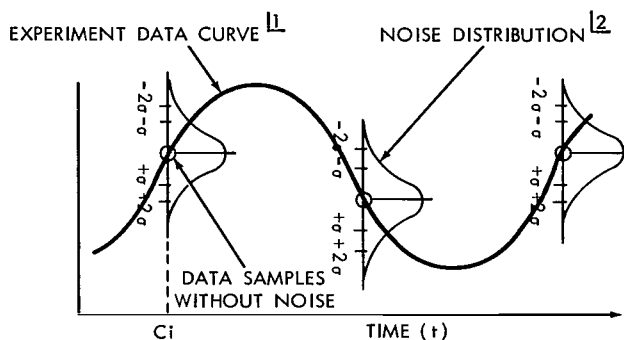
In a similar manner, the user may provide a FLGSUB subroutine for generating a data flag. Again, once each frame, the main program calls the subroutine and provides the current ground time, record number, frame number, and number of errors in a frame synchronization pattern. The user subroutine then computes the value of the flag for insertion in the output record and returns control to the main program.

Code Conversion

Each tape may have a tape label record, and each file may have a file label record. These label records may be specified as either UNIVAC 1107 FIELDATA or IBM BCD code. This selection is based on an input parameter for each label definition.

Satellite Clock Specification

Readings from a satellite clock may be obtained by considering the clock to be another data curve. The starting value of the clock, as is true for all data curves, is an input parameter. Normally, the stair-step type of curve will be chosen for the clock simulation. Since the amplitude of the stair-step determines the increment of the clock update, it would be assigned a value of one. Depending on the other input parameters, the clock updates may be made to be either synchronous or asynchronous. The term synchronous, as used here, refers to the case in which the time source for the clock update is synchronized with, or taken from, the same source as that used for generating the telemetry frames. The term asynchronous is used when the time source for the clock update is independent of the time source for the telemetry frame generator. In the former case,



$$1 \quad X(t) = X_i + A_i \sin \left[\frac{2\pi}{P_i} (t - C_i) \right] + n$$

WHERE:

A_i , P_i , C_i ARE AS DEFINED IN FIGURE 3,

$$P(n) = \frac{1}{\sqrt{2\pi}\sigma} e^{-n^2/2\sigma^2}$$

σ IS AN INPUT PARAMETER,
AND n RANGES FROM $0 \rightarrow \pm 5\sigma$

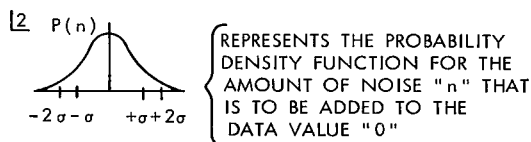


Figure 4—Experiment data with sensor noise.

the clock is essentially a frame counter, whereas in the asynchronous case the number of frames between clock updates will likely be greater than one and will fluctuate throughout the file.

If the satellite clock characteristics are more complex than can be simulated through use of the stair-step curve, a user subroutine may be substituted.

Ground Time

An associated ground time is generated for each frame of data. It is used, among other things, to determine the point along the data curve where the sample is to be taken for a given frame for those channels which are time-dependent. Ground time is simulated by specifying the start time and the elapsed time per frame. Frames will continue to be generated until the user-specified stop time is reached for a given file. The ground time generated for a given frame relates to the first bit of the first channel defined for that frame. Various types of errors in ground time, described later on, may be simulated; however, these errors do not affect the proper selection of the sampling points for the data channels as previously mentioned.

Data Perturbations

Ground Signal Processing

Satellite telemetry data are converted from their analog form to a digital magnetic tape suitable for direct computer input by means of a STARS (Satellite Telemetry Automatic Reduction System) processor. In addition, the STARS processor decodes the ground time and generates flags with each frame of data to indicate the data and ground time integrity. The flags indicate:

- a. number of errors in the frame synchronization pattern for the given frame.
- b. incorrect BCD or serial decimal time.
- c. one or more parity errors within the frame.
- d. loss of frame synchronization or subcommutator synchronization.

The operation of the STARS processor is simulated by the computer program, including the logic used to maintain frame and subframe synchronization. One or more losses of frame or subframe synchronization during a given file can be made to occur, depending on the user's choice of input parameters. Also, any combination of the above flags may be generated and recorded on the output tape in the designated format.

Transmission Noise

Transmission noise is simulated according to input parameters such as bit error rates, signal blanking, and bit slippage. The bit error rate for a given file is applied to each data sample by generating a random number between zero and one for each bit of the sample value. When the

random number is less than the bit error percentage, the corresponding bit is complemented (thereby resulting in an error).

Signal blanking simulates loss of signal, and hence the loss of synchronization during the analog-to-digital conversion, for short durations. The bit error percentage during these intervals is then temporarily 50%. The frequency of occurrence of signal blanking is controlled by an input parameter, but the elapsed time of each occurrence is selected at random and the number of frames lost can vary between 5 and 20 frames.

Bit slippage is the condition where the time between successive bits in the telemetry stream changes to the extent that the cumulative effect is at least equal to one-half the bit time. The number of bits per telemetry frame is thus in error. This usually causes the STARS processor to lose synchronization, as described previously. Forward and backward bit slippages of single and multiple bits may be generated by inputting a bit slippage probability for the file. At the beginning of each frame, a random number is generated and tested against the bit slippage percentage input by the user. If the random number is less than the slippage percentage, the position of the slip within the frame and the magnitude and direction of slip are computed, using additional random numbers.

Satellite Telemetry System Malfunctions

Many satellite telemetry malfunctions may be simulated. Two such cases are presented here.

Subcommutator slippage is defined as an incorrect updating of the satellite subcommutator position. Both the probability of an erroneous subcommutator updating and the value of the incorrect increment are input parameters. Each time the subcommutator is sampled, a determination is made according to the specified probability as to whether an error is to be introduced. The direction of the position error may be either positive or negative, and may be independently specified for each of five subcommutators.

Irregularities can be made to occur in simulating the satellite clock readings. Random errors which are normally distributed can be specified with any frequency of occurrence, as described previously under Experiment Data Characteristics. However, if other than random noise is desired, it can likely be achieved by defining additional curves for the same channel. Such things as forward time jumps, temporary changes in clock speed, and clock re-setting can all be accommodated in this manner.

Ground Equipment Malfunctions

Problem files which result from ground equipment malfunctions can easily be obtained. One such possibility is erroneous ground time. Four types of errors, in any combination, can be reflected in the ground time values. The frequency of occurrence of each type of error is controlled by the user's input parameter. The four types of time errors will be controlled by error percentages, which are input to the program. The errors consist of bias errors, rate errors, single time discontinuities, and suspect time. Bias errors, for example, may be introduced by the time

encoder or decoder. Rate errors simulate telemetry bit rate instability, or time decoder fly-wheeling due to loss of signal. Single time discontinuities occur during momentary decoder malfunctions. Suspect time is indicated by the time quality flag which, if requested, is inserted with each frame of data. In actual practice, suspect time covers the case where the ground time appears to be correct, but it does not fully meet all the validity checks that are performed by the STARS line in the analog-to-digital conversion process.

Other types of ground data processing equipment (both STARS processing and digital computers) malfunctions may be simulated. Such items as incorrect tape formats (described next), incorrect record length, parity, and density can all be introduced by the user. Record lengths may be short or long, with the size randomly chosen between zero and twice the normal length. Tape parity errors are simulated by generating a record of opposite parity to that specified. Tape density errors are handled in the same manner by generating a record of incorrect density 200 or 556 characters per inch.

Operator Errors

Several types of operator errors which result in incorrect tape formats are provided, such as the omission of an end-of-file (EOF) mark, or the presence of an extra end-of-file mark at the end of the data file. Another type of error is the omission of a file label record at the beginning of a file. Note that equipment malfunctions could cause the above errors in a similar manner.

The user can exercise the above options to extend the normal formatting capability of the program. These options allow the user to obtain one file having two different formats, as is possible with the OGO satellite. In this case the second format would be defined as a second file by having the user specify no end-of-file mark for the first file, and no label record for the second file. The generated data would then appear as one consecutive file.

Tape and Printer Outputs

The tape format will, in general, appear as in Figure 5. The format may be modified as just described. All input parameters for a given run are listed with suitable identification. This is followed by printouts of each data value for selected channels. In addition, every n^{th} output tape record may be printed if desired. Error conditions are also listed. These include time errors, bit slippage, signal blanking, subcommutator slippage, tape parity errors, etc. Appropriate identification, e.g. the type of error and frame number where the error occurred, is included with each error. At the completion of each file summary, statistics of data quality are printed.

Computer Time Required

Because of the complexity of the simulation, no simple formula has been derived for the UNIVAC 1107 time required for a given problem. However, to provide some feel for the time involved, results of an actual computer run are given. A simulation for the Atmosphere Explorer-B satellite was performed with the following parameters:

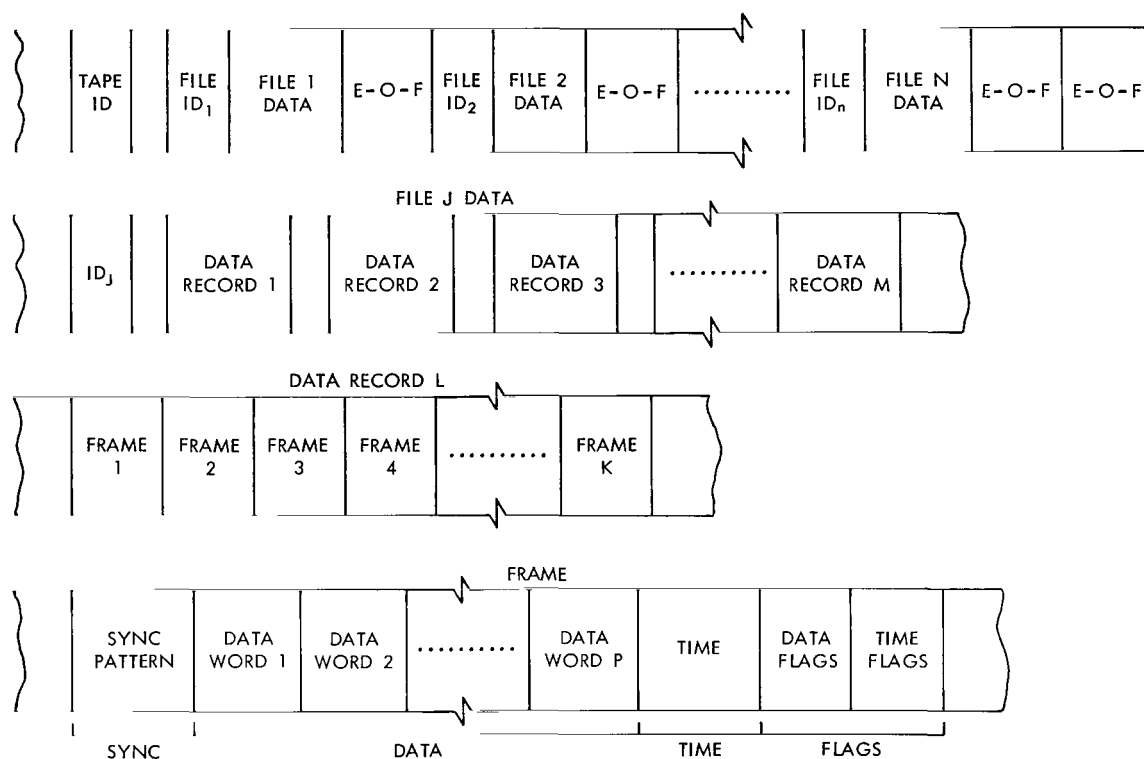


Figure 5—Tape format.

48 words per frame,
 9 bits per word,
 32 frames per record, and
 10^4 frames simulated.

In this case, an average of 100 milliseconds of computer time was required for each frame simulated.

User Information

To fully exploit the potential benefits offered by the Data Simulation Program, all NASA personnel (including programmers, analysts, supervisors, and experimenters) involved in defining computer program specifications and writing computer programs are encouraged to avail themselves of this service. Any NASA center may request a copy of the program and appropriate documentation, in order to run the program on a UNIVAC 1107 or 1108 computer, which may be more readily accessible than the GSFC facility. For those desirous of using the GSFC 1107 computer, such requests will be accommodated on a time permitting basis. Requests should be directed to the Data Simulation Project, Data Processing Branch, Information Processing Division, Goddard Space Flight Center, Greenbelt, Maryland.

(Manuscript received March 10, 1966)

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